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Disaster Management Using D2D Communication With Power Transfer and Clustering Techniques

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ABSTRACT Device-to-device (D2D) communications as an underlay to cellular networks can not only increase the system capacity and energy efficiency but also enable national security and public safety services. A key requirement for these services is to provide alternative access to cellular networks when they are partially or fully damaged due to a natural disaster event. In this paper, we employ energy harvesting (EH) at the relay with simultaneous wireless information and power transfer to prolong the lifetime of energy constrained network. In particular, we consider a user equipment relay that harvests energy from radio frequency signal via base station and use harvested energy for D2D communications. We integrate clustering technique with D2D communications into cellular networks such that communication services can be maintained when the cellular infrastructure becomes partially dysfunctional. Simulation results show that our proposed EH-based D2D clustering model performs efficiently in terms of coverage, energy efficiency, and cluster formation to extend the communication area. Moreover, a novel concept of power transfer in D2D clustering with user equipment relay and cluster head is proposed to provide a new framework to handle critical and emergency situations. The proposed approach is shown to provide significant energy saving for both mobile users and clustering heads to survive in emergency and disaster situations.

INDEX TERMS D2D, SWIPT, UERCH, energy harvesting, clustering.

I. INTRODUCTION

COMMUNICATION is one of the biggest problems in disaster situations. Many people around the world are adversely affected by various unforeseen disasters such as earthquakes, tsunami, floods and torrential rains. Although disasters differ according to the nature and the context in which they occur, their management faces almost the same and repetitive problems which are mainly related to the complexity of the field, the interoperability issues and the sociocultural aspects. Effective emergency and natural disaster communication system depend on the efficient mission-critical voice and data communication between first responders and victims [1]. The limitations which restrict the realization of information communications are [2]: (i) Communication infrastructures are not available; (ii) Loss of energy/power; (iii) Low reliability and availability of network; and (iv) Limited resources and limited services.

Situations like disasters (earthquakes/tsunamis) need power saving, less energy consuming devices and networks. Certainly, energy consumption is a key area nowadays in public safety networks. In addition to this, the breakdown of essential communications is one of the most commonly shared characteristics of all disasters. Whether partial or complete, the failure of telecommunications infrastructure leads to unavoidable loss of life by causing delays and faults in emergency response of disaster relief. In many situations, the reason for the disconnection of communication networks is due to the breakdown of power networks. Although some small communication devices run on batteries, their power may run out quickly. Therefore, recovery of power supply is critical for disaster recovery.

In order to cope with this critical issue, energy harvesting (EH) is capable of powering communication devices and networks with the energy harvested from the environment. Recently, the EH has become an appealing solution to prolong the life time of wireless networks. The EH potentially has an unlimited energy supply from the environment in the form of renewable energy sources like solar and wind energy. Therefore, the research in renewable energy drawn a great attention particularly in cellular communication [3]. In addition, in disaster situations energy efficiency is even more important in terms of robustness and availability than in normal conditions. Solar panel and wind turbine do not justify the scalability and reliability to situation. Therefore, ambient energy radio signals can be viable new resource for wireless energy harvesting (WEH) where the radio frequency (RF) systems have the capability of converting the received signals into energy source [4]. The system becomes a promising solution to energy constrained wireless networks. As the energy is particularly limited in emergency situations, RF energy can become an excellent choice for the power and information exchange.

Simultaneous wireless information and power transfer (SWIPT) has developed as a promising technology, allowing the transmission of data and energy together to a receiver equipped with an RF energy-harvesting circuitry. Moreover, SWIPT is capable of delivering suitable and continuous energy provisions to the wireless networks. This accordingly motivates us to investigate the SWIPT and its connotation in disaster communication systems because of its significant attentions and also to be considered as an emerging technology. In a communication system with SWIPT capabilities, information and power transfer are carried out over wireless medium simultaneously. Two practical schemes for SWIPT, namely *time switching* (TS) and *power splitting* (PS), were proposed in [5].

Based on our previous work [6], we propose a disaster communication architecture based on Device-to-Device (D2D) communication. D2D is one of the new technologies being considered for achieving higher system throughput by taking advantage for short distance, direct communications and multi users diversity. Furthermore, integrating D2D into the LTE-Advanced (LTE-A) system offers the prospect of a spectrum-efficient, energy-efficient and secure solution for proximity discovery and D2D communications. The proximity based services of D2D technology also satisfy the need of Public Safety Networks (PSNs). In particular, we consider a D2D based energy EH cellular network where the relay and user equipment relay (UER) harvest RF energy from a base station (BS) and use the harvested energy for the D2D communications. Further, we employ user-cooperation based clustering scheme to minimize the average power consumption of user equipments (UEs).

This paper has the following contributions: i) This research develops a framework which has adopted an innovative approach to apply TS protocol at relay to provide energy and information to further strengthen the life of relay based network during disaster events; ii) Mode selection strategy is adopted to analyse the suitability of D2D communication and the employment of the UER during disaster to harvest energy from the relay via BS so that the energy is sustained for D2D communication; iii) This research contributes to the understanding of the effects of the network parameters on the outage probability of the D2D mode; and iv) A novel cooperative D2D energy harvesting clustering network for disaster management is developed to enhance performance, reliability and energy efficiency. The network is shown to be resilient and scalable for large number of users. It helps minimize impact of the limitation of resources and services to overcome major problems during disaster events such as power loss, traffic congestion and network capacity.

The rest of this paper is organized as follows: Section II summarizes the related work. Section III provides a system model for analysing the energy harvesting technique and D2D performance in term of outage probability in the scenario of disaster. Section IV describes a framework for disaster recovery using D2D, clustering and EH. Section V discusses simulation results, performance of D2D and EH with clustering. Section VI concludes the paper.

II. RELATED WORK

Recently, it has been observed in Italy, Nepal, and New Zealand that due to the earthquakes most of the existing networks were completely destroyed in the disaster areas. This affected local people significantly and made the first responders' tasks very difficult. A large number of victims were trapped in the disaster zones for several days. Such big-scale disasters require a public safety network system that can operate efficiently in disaster situations. The research community has attempted to propose various disaster-resilient networks on the basis of earlier disasters experiences and related projects around the world. The common goal of all the efforts is to design network architectures and provide solutions that are resilient to disasters.

During those above disaster situations, Facebook activated its Safety Check feature to enable people to give quick safety status updates to their family and friend during the disaster [7]. Popular social media tools like Twitter and Facebook were flooded with messages for requests and help. It was observed that on the disaster sites, local people had little capacity to gather and arrange the large amount of information coming in. This has led to the demand to investigate the limitations of the cellular networks to handle the traffic in those critical situations. Fortunately, D2D communication effectively uses the radio resources with the goal of serving a large number of affected people to collect information from different nodes in the disaster zone [8]. Nishiyama *et al.* [10] developed a prototype, namely Relay by Smartphone, of D2D relaying smartphone that enables sending out emergency messages from disconnected areas and sharing of information between people gathered in evacuation centres. In [9] a novel D2D based messaging solution to overcome the UE power limitation issues faced by cellular radio access technologies in disaster situations was presented. The proposed D2D messaging mechanism was compared with the default Random Access Channel (RACH) based messaging mechanism. However, in this work the RACH based power consumption was not explicitly modelled for various radio access technologies (e.g., Global System for Mobile Communications (GSM), Universal Mobile Telecommunications Systems (UMTS) and Long-Term Evolution (LTE)), and therefore further study is needed to evaluate the power consumption.

According to the requirement of public safety network, wireless networks are ideal choice for disaster relief operations as wireless networks do not need any pre-existing infrastructure to be set up and are easy to operate in critical situations. However, energy management is a big concern for such infrastructure. Therefore, some recent studies have considered energy harvesting through the RF signals in wireless cooperative networks. Chalise *et al.* [11] considered a multiple-input multiple-output (MIMO) relay system and studied the trade-off between the energy transfer and the information rate to achieve the optimal source and relay precoding. However, they assumed that the relay has its own internal energy source and does not need external charging. In contrast to [11], in our work we consider that the relay also relies on external wireless charging through the RF signal from the source node. Lee [12] presented hybrid power transfer architecture with power relay. Airships, helicopters and balloons are used to transfer power wirelessly through inductive power transfer to big communication devices and through microwave power transfer to small communication devices. Differently, we use efficient and practically workable BS and relay to transfer energy wirelessly to the destinations.

The work in [13] investigated renewable energy enabled base station (REBS) and pre-equipped energy harvesting devices, performing in wireless mesh network fashion, for post-disaster communication scenarios. Particularly, the authors focused on optimizing data traffic throughput with lowest weighted energy consumption, in which they proposed an off-line energy efficient scheme using the expectation of traffic demands. In addition, for better energy consumption and management in future cellular networks, Nahas *et al.* [14] proposed a new algorithm to help in reducing energy consumption of heterogeneous LTE networe (HetNet) using macro and micro base stations and cell zooming. The solution is carried out through introducing new cell sizes (micro, pico and femto cells) with various capacities, coverage areas and lower power consumption by operating all together existing base stations in a heterogeneous network. However, the existing scholarly works have focussed mainly on reducing the energy consumption of BS via HetNet and cell zooming, wheares in our paper we develop extended communication links in the disaster area by adopting EH-D2D technique and clustering method. In [15], resource unit concept called Movable and Deployable Resource Unit (MDRU) was presented by Nippon Telegraph and Telephone (NTT) Corp.. The idea of MDRU is to transport complete resource unit to the disaster site and deploy recovery network. However, the cost of making an MDRU is very high, and the MDRU deployment may not be practical considering that spectrum and energy resource in an disaster area are significantly limited while the demand of network connectivity, capacity and power often increases with time during and after disaster. Altay *et al.* [16] proposed a standalone eNode-B architecture, which deploys its own integrated virtual evolved packet core (EPC) to ensure service without backhaul connection. The proposed standalone eNode-Bs are also designed to establish backhaul connection with each other to extend the coverage without need of a central EPC structure. The concept of eNode-B not only offers better interoperability but also increase functionality in terms of transmitting data especially in emergency situations and disaster scenarios. However, the work in [16] did not address the power consumption issue during the disaster events. In [17], the effect of the relay mobility was addressed, where the authors considered the coverage and capacity extensions by mobile relays, and the influence of mobility on the probability of route establishment and the expected availability duration. However, this work limits their scope to point-to-point communication with single cell in idealized circular coverage area, whereas here in our work we address the communication links across the entire network of multicell multihop where the network coverage is extended beyond a single cell using D2D relay links.

III. SYSTEM MODEL AND OUR APPROACH

Mobile communications with D2D proximity have unique topographies which are valuable in disaster and emergency situations. As long as BS is up and running or an ad-hoc process can manage to provide reliable communications (relay system), wireless links can be easily established between users within its coverage area or with extended options.

A. DISASTER MANAGEMENT ARCHITECTURE

We consider a public safety scenario as shown in Fig. 1, where a source (i.e., BS) with a fixed energy supply desires to transmit its information to a destination located in the out of coverage area. Due to the barrier between the source and destination or direct link distance, the source cannot directly transmit its signals to the destination; thus it asks a relay to assist its information transmission via D2D communication proximity services since destination is in a disaster area where direct communication is not possible. However, because of the selfish nature, or lack of energy supply, the relay needs to harvest energy before being able to help. Throughout this paper, the following set of assumptions are considered.

Assumption 1: A wireless D2D communication system is considered, where the information is transferred from source S to destination node D, through intermediate relay node R as shown in Fig. 1. The destination node D can then act as a User Equipment Relay (UER) node in another hop in the disaster area. Further, UER acts as a cluster head (UERCH) in clustering formation phase.

Assumption 2: The intermediate node R is an energy constrained node. It first harvests energy from the S then uses the harvested energy as a source of transmit power to forward the source information to the destination.

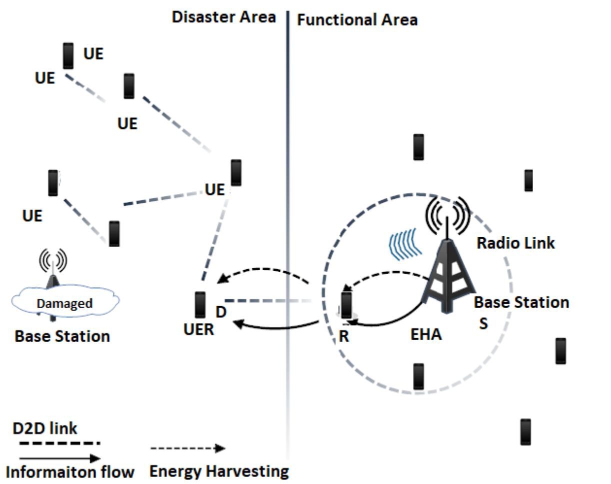

FIGURE 1. Energy harvesting concept in disaster situation.

Assumption 3: Relay node is selected to forward the signals and energy to the destination only if it has sufficient energy or is able to harvest energy from the source. Amongst the different relaying protocols, Decode and Forward (DF) scheme is chosen at the relay node.

B. TIME SWITCHING BASED PROTOCOL

The TS based protocol is adopted at the relay, where T denote the block time in which a certain block of information is transmitted from the *source* node to the *destination* node with TS ratios α_1, α_2 and α_3 where $\alpha_1 + \alpha_2 + \alpha_3 = 1$. During the first time slot with duration of $\alpha_1 T$, the source transfers energy to the relay. In the second time slot $\alpha_2 T$, the source transmits signal to the relay while in $\alpha_3 T$ the relay forwards signals to the destination. There is no direct link between the source and the destination node.

Assume that in relay network the total bandwidth is divided into N orthogonal sub-carriers, $n \in N = 1, 2, 3, ..N$ and the network comprises two wireless links i.e., source to relay and relay to destination links as h_n^{SR} and h_n^{RD}, respectively. We further assume that $h_n^{SR} \propto d_{SR}^{\alpha}$ and $h_n^{RD} \propto d_{RD}^{\alpha}$ where α is the pathloss exponent and d_{SR} and d_{RD} are the distances between source and relay and between relay and destination, respectively. The energy harvested at the relay during the first time slot can be expressed as [5]:

$$E = \alpha_1 T \zeta \sum_{n=1}^{N} p_n^{S,1} \mid h_n^{SR} \mid^2 \tag{1}$$

where $p_n^{S,1}$ represents the transmit power of the source (i.e., BS) over n^{th} sub-carrier for energy transfer and ζ denotes EH efficiency. To maximize harvested energy at the relay, the source should assign all available power over the sub-carrier that has a maximum channel gain. Therefore, we have

$$E = \alpha_1 G \tag{2}$$

where

$$G = T \zeta P \max_n \mid h_n^{SR} \mid^2 \tag{3}$$

and P represents the maximum transmit power of the source for both energy and information transmission. We have $P \geq \sum_{n=1}^{N} p_n^{S,1}$. Then, the source transmits signals to the relay over N sub-carrier in the second time slot. After receiving the signals relay decodes the signals, redistributes the decoded signals over different sub-carriers and forwards the signals to destination. Therefore, the maximum achievable end-to-end data rate of DF relay network is obtained as [19]

$$C = min\left[\alpha_2 \sum_{n=1}^{N} \log_2(1 + p_n^{S,2}\gamma_n^{SR}), \right. \\ \left. \alpha_3 \sum_{n=1}^{N} \log_2(1 + p_n^{R}\gamma_n^{RD})\right] \tag{4}$$

where $p_n^{S,2}$ and p_n^R represent the transmit power of source and relay over n^{th} sub-carrier for information transmission, respectively; $\gamma_n^{SR} =\mid h_n^{SR} \mid^2 / \sigma_R^2$ and $\gamma_n^{RD} =\mid h_n^{RD} \mid^2 / \sigma_D^2$. Here, noise powers over each sub-carrier at relay and destination are represented by σ_R^2 and σ_D^2, respectively. It is also noticed from [20] and [21] that the harvested energy in the first time slot should be larger than or equal to the consumed energy for information transmission at the relay i.e,

$$E \geq \alpha_3 T \sum_{n=1}^{N} p_n^R. \tag{5}$$

Note that there are possibly numerous nodes between source and destination, which are candidates to perform as a relaying node. Here we need to define the best relay node before information and energy transfer.

Relay node selection has already been discussed in our earlier work. It is assumed that the BS knows every channel in the field. So, it can simply determine which node can act better in the area. In order to harvest energy, the received power of a relay from its nearby BS should not be small. We define the area around the BS called *energy harvesting area (EHA)*, which is circle with the radius R_{ha} centered at BS as shown in the Fig. 1 and the R_{ha} is given by

$$R_{ha} = \left(\frac{\zeta P_{bs}}{B_w}\right)^{1/\nu} \tag{6}$$

where $\zeta \in (0, 1)$ is the energy harvesting efficiency factor of *UE*, P_{bs} transmit power of the BS, B_w is the energy harvesting threshold to activate the EH circuit and ν is path loss exponent in EH transfer link.

C. NETWORK CONFIGURATION

As shown in Fig. 1, we consider a cellular network which consists of BS capable of performing wireless power transfer and relay that can harvest energy from their nearby BS. We assume that the distribution of the BS in the network follows homogeneous Poisson Point Process (PPP) Φ_{bs} with spatial density λ_{bs} and UEs are also distributed according to a homogeneous PPP Φ_{ue} with spatial density λ_{ue} while relay spatial density is λ_r. The transmit powers of a BS, relay and UE are P_{bs}, P_r and P_{ue}, respectively. When a relay has sufficient harvested energy then it can help the BS to forward the information to another hop in the non-functional area node in DF manner and with signal-to-interference ratio (SIR). The node acts as a UER and the communication between a relay and the destination UE is taken place between two user devices, which is D2D communication. As we know that, UEs can not communicate with a BS for their own data so, we also assume that each UER receives the data for itself with probability p_{rc} and p_r is the probability that an UE can support other UEs as an UER. Moreover, when an UER does not need to receive its own data and has the amount of harvested energy exceeding $E_{ue} = NB_w$, the UER can help another UE using E_{ue}. Load ρ_{bs}, as BS using the same spectrum at any random time slot, is expressed as [22]

$$\rho_{bs} = \frac{p_{rc}\lambda_r}{\lambda_{bs}N}. \tag{7}$$

D. OUTAGE PROBABILITY FOR MODE SELECTION

Applying relaying techniques to D2D communication scenarios has attracted much attention recently due to its ability to enhance D2D coverage and reliability. End-to-end outage probability is investigated here to confirm whether D2D technology could be a preferable option or not in our scenario (mode selection). First, we determine the outage probability of an UER that operates in D2D mode. The distance between BS and R is d_1 and the distance between R and an intended UER is d_2, the outage probability of D2D mode can be presented as

$$P_{out} = 1 - \exp\left\{-\xi(\theta_d,\alpha)\left(\rho_{bs}\lambda_{bs}d_1^2 + \frac{p_r\lambda_r}{N}d_2^2\right)\right\} \tag{8}$$

where α is path loss exponent in data link and θ_d is the SIR threshold for D2D mode transmission and $\xi(\theta_d,\alpha)$ is given as,

$$\xi(\theta,\alpha) = \frac{2\pi^2}{\alpha}csc\left(\frac{2\pi}{\alpha}\right)\theta^2/\alpha. \tag{9}$$

In the D2D mode transmission, the outage occurs when at least one of the two links (BS to R, and R to UER) does not achieve the target SIR θ_d. Consider that in the Fig. 1 the BS locates at (x_s, y_s), R locates at (x_r, y_r), and UER locates at (x_d, y_d), then we can have $d_1^2 = (x_r - x_s)^2 + (y_r - y_s)^2$ and $d_2^2 = (x_d - x_r)^2 + (y_d - y_r)^2$. The outage probability in (8) can now be rewritten as

$$P_{out} = 1 - \exp\{-\rho_{bs}\lambda_{bs}\xi(\theta_d,\alpha)f(x_r, y_r)\} \tag{10}$$

where

$$\begin{aligned} f(x_r, y_r) = \|(x_s - x_r\|^2 + \|(y_s - y_r\|^2 \\ + \Lambda\|(x_r - x_d\|^2 + \Lambda\|(y_r - y_d\|^2) \end{aligned} \tag{11}$$

and Λ is given as

$$\Lambda = \frac{p_r\lambda_r}{N\rho_{bs}\lambda_{bs}}. \tag{12}$$

The optimal location of R that minimizes P_{out} is obtained by

$$\begin{aligned} (x_r^o, y_r^o) &= \arg\min_{\{x_r,y_r\}} P_{out} \\ &= \arg\min_{\{x_r,y_r\}} f(x_r, y_r). \end{aligned} \tag{13}$$

By taking partial differentiation of $f(x_r, y_r)$ with respect to x_r and y_r separately and equate it to zero, we can achieve the optimal location of R as follows

$$(x_r^o, y_r^o) = \left(\frac{x_s + \Lambda x_d}{1+\Lambda}, \frac{y_s + \Lambda y_d}{1+\Lambda}\right). \tag{14}$$

Now, using the optimal location of R, the outage probability can be represented as

$$\begin{aligned} &P_{out}(x, d_o) \\ &= 1 - exp\Big\{-\rho_{bs}\lambda_{bs}\xi(\theta_d,\alpha)\Big(\frac{\Lambda x^2}{1+\Lambda} + (1+\Lambda)d_o^2\Big)\Big\} \end{aligned} \tag{15}$$

where x is the distance between a source and the UER, and the d_o is the distance between the optimal R location (x_o, y_o) and the actual R location. From (15) and (17), we can see that R is a circle centered at (x_o, y_o). The radius of this circle can be used to determine whether the outage probability is satisfactory. If it is then we can conclude that the UER is in the D2D selection mode and will use the nearest R from the optimal R location for its further communication.

This transmission mode selection can be useful to exploit the D2D energy harvesting network (EHN) communication efficiency. Therefore, it is useful to study the outage probability of the D2D-EHN by considering the transmission mode selection and the energy harvesting as follows

$$\begin{aligned} P_{out} = &\frac{\rho_{bs}\lambda_{bs}\xi(\theta_d,\alpha)(1+\Lambda)}{\lambda_r\pi + \rho_{bs}\lambda_{bs}\xi(\theta_d,\alpha)(1+\Lambda)} \\ &\times \frac{\lambda_r\kappa^2\pi + \rho_{bs}\lambda_{bs}\varphi(\theta_b,\alpha)}{\lambda_{bs}\pi + \lambda_r\kappa^2\pi + \rho_b\lambda_{bs}\varphi(\theta_b,\alpha)} \\ &+ \frac{\lambda_r\pi}{\lambda_r\pi + \rho_{bs}\lambda_{bs}\xi(\theta_d,\alpha)(1+\Lambda)} \\ &\times \frac{\xi(\theta_d,\alpha)\rho_{bs}\lambda_{bs}\Lambda}{\lambda_{bs}\pi(1+\Lambda) + \xi(\theta_d,\alpha)\rho_{bs}\lambda_{bs}\Lambda}. \end{aligned} \tag{16}$$

where

$$\kappa = \sqrt{\left(\frac{\varphi(\theta_b,\alpha)}{\xi(\theta_d,\alpha)} - \frac{\Lambda}{1+\Lambda}\right)\frac{\Lambda}{1+\Lambda}} \tag{17}$$

and

$$\begin{aligned} \lambda_r &= \lambda_{ue}p_a(1-p_{rc}) \\ &= \frac{\lambda_{ue}p_r^{-1}(1-p_{rc})\left(1 - e^{-\pi\lambda_{bs}R_h^2}\right)}{1 - e^{-\pi\lambda_{bs}R_h^2} + N} \end{aligned} \tag{18}$$

and

$$\begin{aligned}\varphi(\theta,\alpha) &= \frac{2\pi\theta^{2/\alpha}}{\alpha}\mathbb{E}\left[h^{2/\alpha}\left(\Gamma\left(-\frac{2}{\alpha},\theta h\right)-\Gamma\left(-\frac{2}{\alpha}\right)\right)\right]-\pi \\ &= \frac{2\pi{}_2F_1\left(1,1+\frac{2}{\alpha},2+\frac{2}{\alpha},-\frac{1}{\theta}\right)}{(2+\alpha)^{\theta}} \\ &\quad -\frac{2\pi^2\theta^{2/\alpha}}{\alpha}csc\left(\frac{2\pi}{\alpha}\right)-\pi.\end{aligned}$$

Here, h is the channel gain which experiences Rayleigh fading, ${}_2F_1(a,b;c,x)$ is the hypergeometric function. We assess the performance of the system and prove that D2D is the favorable option for communication in disaster situations.

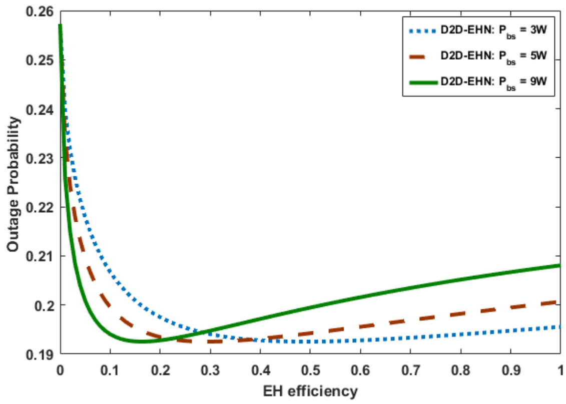

FIGURE 2. Outage probability as a function of energy efficiency for different values of BS power(P_{bs}).

As shown in Fig. 2, we observe that an optimal efficiency value exists and shifts towards zero as P_{bs} becomes larger. For D2D EHN with P_{bs} = 3W, P_{out} reduces exponentially as the EH efficiency increases, but with P_{bs} = 5W, P_{out} reduces exponentially till that EH efficiency is equal to 0.5. After that, P_{out} increases steadily. Moreover, with P_{bs} = 9W P_{out} decreases dramatically till the EH efficiency value of 0.2 and then increases linearly subsequently. As a result, there are more chances to adopt UEs to select D2D mode for the purpose to reduce the outage probability. For larger P_{bs}, we observe that the UER density increases dramatically with ζ, which means that it leads to increasing the number of UERs and each UE has a high chance to communicate in D2D mode.

Figure 3 shows the outage probability (P_{out}) as a function of p_{rc} (i.e. probability by which an UER receives data for itself). When a UER is receiving its own data from the R, it is incapable of serving as an UER. We observe that P_{out} is increasing when p_{rc} increases. Moreover, using D2D communications reduces P_{out}, especially with high EH efficiency. Higher values of EH efficiency factor reduce p_{rc} which increases the effect on P_{out}, and it stabilizes around the value of 0.07. As shown in Fig. 4, outage probability as a function of P_r (i.e. probability that a UE can support other UEs as a UER) for different values of EH efficiency. Outage probability increases as P_r increases but in different manners: exponentially in absence of D2D communications

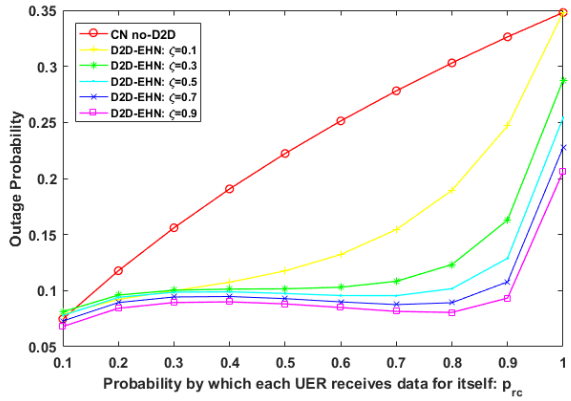

FIGURE 3. Outage probability as a function of p_{rc} for different values of ζ.

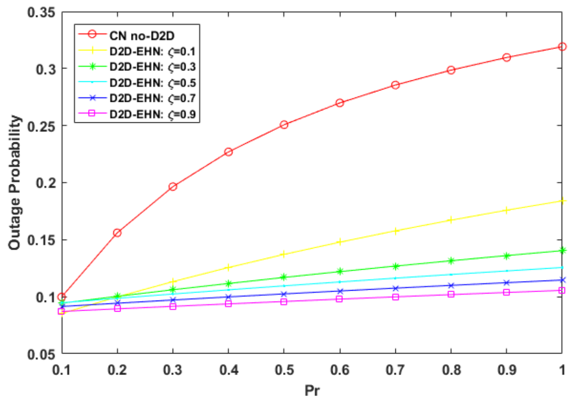

FIGURE 4. Outage probability as a function of p_r for different values of ζ.

and linearly when D2D communications applies. This makes the prediction of the D2D outage probability possible. When a UER has harvested sufficient energy and served as a UER, it can then be solicited by other UEs to relay their data and connection.

IV. POWER TRANSFER USING RELAYING AND CLUSTERING IN D2D MODE

A. OUR APPROACH

In previous section, we aimed to send signals from functional area to non-functional area with the help of a network relay. We also implemented energy harvesting technique so that the relay could be active in the field and further passes the energy and information in to the disaster area as per requirement of the system. Now, in this section we are presenting a novel approach by using clustering techniques in D2D relay mode to facilitate communication of multiple users that are affected within the disaster area. From the technical perspective, exploiting the nature of proximity may provide multiple benefits in disaster situations like:

- D2D may utilize high data rate and low end-to-end delays.
- Compared to normal cellular communication, direct communication saves energy and improves utilization ratio.

Since network assisted D2D communications take advantage of the cellular infrastructure presences, we propose to build on the D2D underlay concept, but extend it in such a way that allows infrastructure/infrastructure-less operation. According to our scenario, high end capability UE can take over some of the radio access network (RAN) functionalities when one or more BS becomes dysfunctional. Such functionalities including providing synchronization signals and acting as a UER or cluster head (CH). We will use in this paper the concept and functionality of User Equipment Relay and Cluster Head (UERCH). We have observed that the capability of nodes to become a UERCH must be taken into account (e.g. available transmit power, support spectrum or synchronization or radio resource management capability). However, network coverage distinguishes two types of UEs:

Category 1 (Cat-1): The UEs are capable of becoming UERCH, directing the D2D links and managing the resource usage among a group of D2D devices (UEs) associated with them.

Category 2 (Cat-2): The UEs are devices that can only act as cluster member and according to disaster situation they are out of network coverage area and controlled by appropriate Category-1 UEs.

UERCH selection has already been discussed in our previous work [18] where complete flowchart is presented to differentiate between nodes of Cat-1 and Cat-2 category. Furthermore, UERCH depends on the outage probability derived in Section III-D. UERCH node proposed in our architecture depends on nodes broadcasting so-called beacon signal on peer discovery resource (PDR). Li [23] evaluated the impact of network assistance on the performance of D2D discovery algorithms in terms of discovery probability, discover time and consumed energy. In [24] grouping strategies, selection of PDRs, beacon signaling and the setting of beacon transmission probability in each time slot with beacon transmission power were discussed. The authors also highlighted the energy, spectral efficiency and the capability of dynamically reconfiguring the network due to mobility, changing radio conditions and nodes joining/leaving the network.

The key of our approach is to elect which user device should act as UERCH as we are establishing communication link via network relay, so the following points must be considered in reality to select the UERCH:

- *Capacity*: UERCH must have certain functions like dual mode function, which means that they can work in both low and high power mode.
- *Network Coverage*: If the device is able to achieve network coverage, other devices are capable to connect to the network through it. Besides, the network can assist D2D communication and make the system more efficient.
- *Mobility*: If user moves fast, it can easily move out of the current cluster and the stable situation is changed and a UERCH reselection is needed which costs computation and time. Thus, slowly moving or static devices are more suitable to be a UERCH.

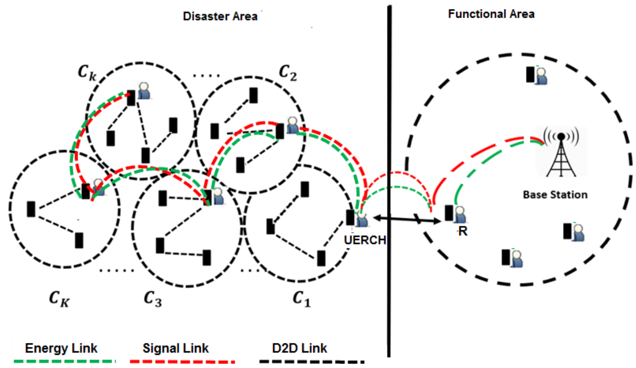

FIGURE 5. Combined System Model Framework for disaster recovery communication using D2D, Clustering and EH.

B. PERFORMANCE EVALUATION OF D2D IN CLUSTERING

In order to cope with disaster situations, a novel cooperative disaster D2D clustering is implemented. For better performance, power transfer relay and D2D clustering methods are adopted to provide novel, robust and stable solution at the time of critical situation. We consider a scenario, in which we successfully establish link from functional area's BS to non-functional area's devices with the help of a network relay. A number of devices can then form a cluster (i.e, coalition) with one device acting as a UERCH and the rest of the devices in the cluster are called cluster members (CM). Moreover, within each cluster D2D communications are adopted to perform content distribution. Data content is sent from BS via R using long range link, as shown in Fig. 5, to the UERCH and then each UERCH send the content to its particular CM via short range link. All the devices operate in D2D mode. At the time of communication each CM receives the content from a single source UERCH. We assume that all nodes can form coalition (see Algorithm 1) where the energy consumption in the coalition is lower than the sum of the individual energy consumptions of the coalition members [25], [26]. Meanwhile, the UERCH also communicates with the relay on behalf of all cluster members. Assume that there are K clusters to be formed, $C_1, C_2, \cdots, C_K$, as shown in Fig. 5. Within each cluster C_k $(k = 1, 2, \cdots, K)$, there are $I_k + 1$ nodes: one UERCH node $n_{k,0}$, and I_k other CM nodes n_{k,i_k}, $i_k = 1, 2, \cdots, I_k$.

Energy Calculation: Consider a communication link between two node $n_{k,u}$ and $n_{k,v}$ $(u, v = 1, 2, \cdots, i_k$ and $u \neq v)$ with cluster C_k. The time needed to transmit a data content of size S_T bits on this link having an achievable rate R_{uv} bps is given by S_T/R_{uv}. Denoting the power drained from the battery of node $n_{k,v}$ to receive the data from node $n_{k,u}$ by $P_{\mathrm{Rx},uv}$, then the energy consumed by $n_{k,v}$ to receive the data from $n_{k,u}$ is given by $S_T P_{\mathrm{Rx},uv}/R_{uv}$. Likewise, representing by $P_{\mathrm{Tx},uv}$ the power drained from the battery of node $n_{k,u}$ to transmit the data to $n_{k,v}$, then the energy consumed by $n_{k,u}$ to

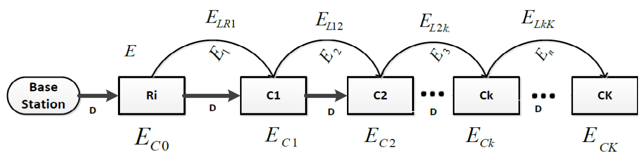

FIGURE 6. Energy loss during transfer of energy.

transmit the content to $n_{k,v}$ is given by $S_T P_{\mathrm{Tx},uv}/R_{uv}$, where $P_{\mathrm{Tx},uv}$ can be expressed as

$$P_{\mathrm{Tx},uv} = P_{\mathrm{Tx}_{ref},uv} + P_{t,uv}, \tag{19}$$

where, $P_{t,uv}$ is transmit power over the air interface on the link between nodes and $P_{\mathrm{Tx}_{ref},uv}$ is the power consumed by the circuitry of nodes during transmission. Denote E_{C_k} as the total energy consumed by cluster C_k, which can be expressed as

$$E_{C_k} = S_T \sum_{u \neq v, u,v=1,2,\cdots,I_k} \left(\frac{\Gamma_k P_{\mathrm{Tx},uv} + P_{\mathrm{Rx},uv}}{R_{uv}} + \frac{P_{\mathrm{Rx},u}}{R_u} \right), \tag{20}$$

where the first term links to the energy consumed by node $n_{k,u}$ to receive the data from R on the large link called cellular link; the second term corresponds to energy consumed by the node $n_{k,u}$ to transmit the data to the other nodes in its cluster on the short link via D2D communication and the last term corresponds to the energy consumed by the nodes to receive their data from node $n_{k,u}$ on the SR. The variable Γ_k is used to differentiate between unicasting and multicasting. In fact, in the uplink process each node has different data to transmit. Hence, only unicasting is used but on the other hand, the same data is transmitted to the member of each cluster in the downlink case.

Considering a single cluster only, the harvested energy (in (1)) should not be smaller that the energy consumption ((20)), leading to:

$$\begin{aligned} E &\geq E_{C_k} \\ \alpha_1 T \rho \sum_{n=1}^{N} p_n^{S,1} \mid h_n^{SR} \mid^2 &\geq E_{C_k} \\ \sum_{n=1}^{N} p_n^{S,1} \mid h_n^{SR} \mid^2 &\geq \frac{E_{C_k}}{\alpha_1 T \rho}. \end{aligned} \tag{21}$$

Assuming power of each subcarrier is the same, (i.e $p_1^{S,1} = p_2^{S,1} = p_N^{S,1} = p^{S,1}$) we should have

$$p \geq \frac{E_{C_k}}{\alpha_1 T \rho \sum_{n=1}^{N} \mid h_n^{SR} \mid^2}. \tag{22}$$

Here, $p^{S,1}$ represents the power of single sub-carrier required for energy recovery as a function of number of devices. This power refers to the necessary single sub-carrier power in such a way that harvested energy from the source in the relay is greater or equal to consumed energy to transmit the signal from relay to destination.

TABLE 1. Simluation parameters.

Parameters	Values	Parameters	Values
B (Bandwidth)	10 MHz	ν	3.76
N_{RB}	50	T	1
S_T (Content size)	1Mbits	Rayleigh parameter	$E[a^2] = 1$
$P_{Tx,SR}$	1.425 Joules/s	Max. $UE_{TXpower}$	0.125W
$P_{Rx,SR}$	0.925 Joules/s	$P_{Rx,LR}$	1.8 Joules/s

Now, we consider multiple clusters to be formed. Each cluster will transfer energy and communicate with the next cluster in a serial multihop manner, as shown in Fig. 6. In addition to the energy consumption E_{C_k}, there will be energy loss when transferring between one cluster to the next, denoted by $E_{L_{(k-1),k}}$.

We therefore propose a coalition formation algorithm (see Algorithm 1) to form the clusters in the most energy-efficient way. In particular, the proposed algorithm is to form the clusters among all the UEs in a way to reduce the average energy consumption. As soon as a UE decides to enter/form a cluster, it enters a binding agreement with the other users within the coalition, and then considers the benefit of the coalition above their individual benefit. Because all the UEs are cooperative and individually rational with this assumption in place, the UEs that are in proximity to one another can form coalitions to provide connectivity and data sharing with each other. We assume that there is an arbitrator/coordinator who makes decisions with respect to the coalition structures, based on the energy profiles of all participating users. The simulation results show that utilization of this coalition clustering algorithm obtains energy efficiency and potentially to be highly efficient in disaster situations as verified in our simulation results.

V. RESULTS AND DISCUSSION

We consider an LTE coverage area with uniform UE distribution. A BS in coverage area transmitting at full power with 10 MHz of bandwidth which is subdivided into 50 RBs of 12 sub-carriers each. Channel and energy consumption parameters for simulation are taken from [25] and [26] and shown in Table 1.

We use Matlab to analyse the impact of UE device variations, energy consumption of UEs, number of UEs and number of clusters in field. A coalition efficiency method was used to carry out simulation which leads to significant energy saving as shown in the results. The scenario investigated in Fig. 5 is based on one BS in the functional area transmitting at full power, while in disaster area the BS(s) are non-functional. In emergency conditions, users located in the non-functional area can take advantage from the D2D UE proximity services. Additionally, D2D relay enhances the data throughput of edge-user(s) that can be used to link far away UEs with cellular coverage to the BS which extends the cellular coverage. We use clustering approach to reduce energy consumption and extend coverage area. A number of UEs form a cluster with one node acting as a UERCH and the rest of the UEs in the cluster are called CMs.

Algorithm 1 Coalition Formation Phases

Initialization
Cluster is formed with its proximity devices
One device act as UERCH $C_k = \{n_k\}$ and $\mid C_k \mid= 1$
All clusters are in search space $S = \{k; C_k \neq \emptyset\}$.

Phase 1 – Cluster and Coalition Candidate Search

Clusters are searched, based on its energy consumption per node. Find the highest energy consumption: $k = \arg\max_{i\in s} E_{C_i} / \mid C_i \mid$
Finding cluster C_j which when merged with C_k will consume lowest energy $j = \arg\min_{i\neq k} E_{C_j \cup C_k}$.

Phase 2 – Coalition formation

do
  if $E_{C_j \cup C_k} \leq E_{C_j} + E_{C_k}$ **then**
    Form a coalition between the members of clusters C_j and C_k
  else
    Work independently
  end if
  if Merger condition is satisfied **then**
    Set $\acute{C_j} = C_j \cup C_k$.
    n_j is the lowest energy consumption cluster head of the new coalition cluster.
  end if
  if Merger condition is not satisfied **then**
    keep cluster C_j and C_k separate
  end if
  Update the clusters, $C_j = \acute{C_j}$ and $C_k = \emptyset$.
while search space $S \neq \emptyset$

In Fig. 7, we have carried out simulation for 100 realizations of UE devices placement (uniformly distributed). The total energy consumption of UEs in non-clustering communication (without D2D) is plotted for varying number of UE devices. We can infer from Fig. 7 that the energy consumption increases with the number of UE devices. Similarly, we have also plotted the total energy consumption of D2D by using coalition cluster formation algorithm for cluster formation and UERCH selection. In D2D communication, UE of each coalition communicates with their respective UERCH and then further each URECH aggregate data from all CMs and transmit it via R to BS in functional area. We compare the total energy consumption of UE devices in both non-clustering and clustering based D2D communication. We observe that, the energy consumption in non-clustering scenario increases exponentially whereas energy consumption increases almost linearly in D2D communication scenario.

We also investigated that impact of different number of UEs per cluster. Fig. 8 is only for D2D scenario with cooperative clustering method by showing the variation in the power of each cluster and the average number of UEs in D2D network by implementing coalition cluster formation algorithm. The average number of clusters is increasing linearly, which means that it is easy to predict the number of clusters by the number of devices. When a UERCH transmits signals to its CM at high power, there are more number of clusters in the network, which means that each UERCH could have less UEs around and this could also save energy and time to transmit data within clusters. Furthermore in Fig. 9, box-plot provides a visualization of summary statistics for sample data. In our

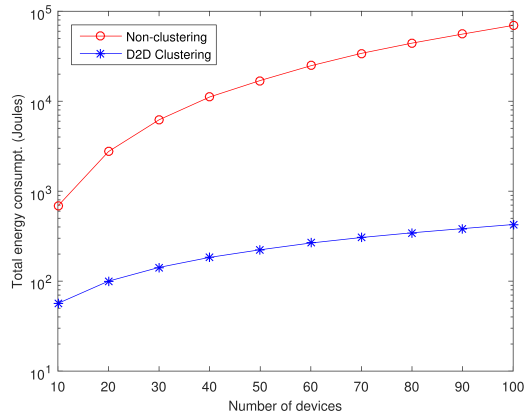

FIGURE 7. Comparison of total energy consumption of UEs devices in non-clustering and D2D based communication.

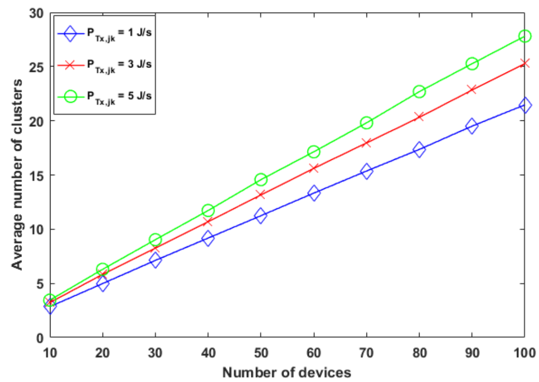

FIGURE 8. Average number of clusters.

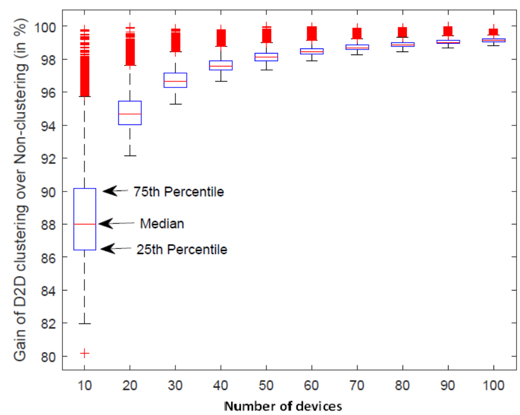

FIGURE 9. Gain of D2D Clustering vs. Non-Clustering Box-plot of Energy gain (in percent) of UE devices in D2D Clustering based over Non-clustering communication for varying number of UE devices.

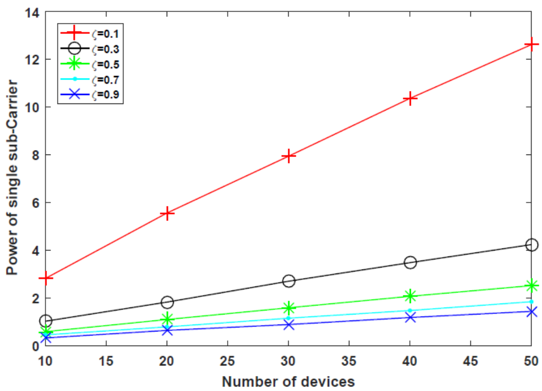

FIGURE 10. **Power of single sub-carrier.**

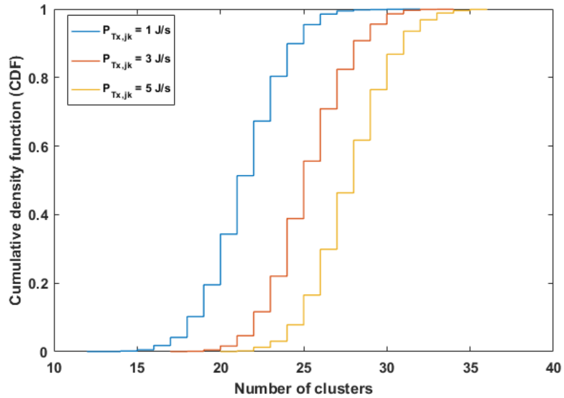

FIGURE 11. **CDF for 100 UEs devices.**

plot, we set outlier as a value that is more than 1.5 times the interquartile range away from the top or bottom of the box. The number of samples we have used to plot Fig. 9 is 100 UE placements × 100 Rayleigh fading realizations. This is equivalent to 10^4 sample points. From the result, we can observe that the energy gain (in percentage) increases with the increase in the number of UE devices. We also note that the variation of energy value decreases with the increase in UE devices (i.e., smaller blue box).

The power of single sub-carrier required for energy recovery as a function of number of devices for various EH efficiency values is shown in Fig. 10. This power refers to the necessary single sub-carrier power in such a way that harvested energy from source is greater than or equal to the consumed energy required to transmit the signal from source to destination ($E \geq E_{C_k}$). This implies that the power of single sub-carrier $p_n^{S,1}$ should be greater than or equal to a threshold. In fact, the represented curve corresponds to this threshold: values of $p_n^{S,1}$ greater than or equal to the curve satisfy the energy recovery equation (21), values of $p_n^{S,1}$ lower than the curve do not satisfy the energy recovery equation, and hence harvested energy is not sufficient to transmit the signal from the source to the destination. We also notice that as the EH efficiency is getting larger, the represented threshold of single sub-carrier power becomes smaller for the same number of devices. This means that when the energy is efficiently harvested, the power threshold is lowered and as a result, the system requires less energy for the sub-carriers and important energy savings would be made.

We also evaluate cumulative distribution function (CDF) for clusters. Fig. 11 shows the CDF of the number of clusters for 100 UE devices. The cluster formation algorithm applied on 100 UEs devices results in less than 25 clusters for 90 percent of time. We can also see that less than 22 clusters are obtained only for 30 precent of time during small power (1 J/s). As we are able to increase the level of power to be received, the formation of clusters will take less time, which accordingly reflects the efficiency of the proposed system. It means that by using this approach we will be able to initiate communications in the disaster area more rapidly. The

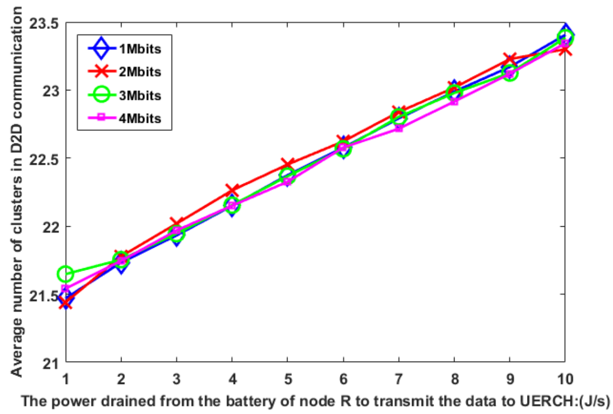

FIGURE 12. **The power drained from the battery The power drained from the battery of relay to transmit the data to UERCH.**

link between relay and the UER is therefore of great significance especially in our proposed PS networks model. Furthermore, deploying clustering and EH techniques to keep the nodes alive and passing information further in non-functional area is a robust physical network design for survivable networks.

The Fig. 12 represents the average number of clusters in D2D communications and power used for transmission (power drained from the battery of node n_k to transmit data to node n_j) for different sizes of transmitted data contents. The number of clusters increases as $P_{T\mathbf{x},jk}$ increases. This means that when a node n_k uses more power to transmit data, it is more likely that the number of formed clusters increases. Moreover, clusters are formed to reduce energy consumption which confirm the results found in Fig. 8 and 9.

VI. CONCLUSIONS

In this article, public safety network and D2D communications were investigated. We have briefly introduced the concept of RF based EH and its applications as well as its potential benefits in this area. We have presented a new design of robust network in disaster and emergency situations. The aim was to provide the optimal communication route for networks in disaster areas, which minimizes the end-to-end disconnection and enables the connection from functional area to non-functional area. The proposed approach was shown to provide significant energy savings for both UE nodes and clustering heads to survive in critical situations like disasters. In addition, our proposed method adds a new step to the provisioning phase for network survivability against network failure and can be executed in an incremental fashion. It can also be combined with other protection and restoration methods to enhance network robustness post-disaster to provide better link connection. Future research directions include the extension of results for the uplink where nodes are not necessarily interested in the same content and further joint power optimization for the multicarrier DF relay network.

REFERENCES

[1] A. Kumbhar, F. Koohifar, I. Güvenç, and B. Mueller, "A Survey on legacy and emerging technologies for public safety communications," *IEEE Commun. Surveys Tuts.*, vol. 19, no. 1, pp. 97–124, 1st Quart., 2017.

[2] K. Ali, H. X. Nguyen, Q.-T. Vien, and P. Shah, "Disaster management communication networks: Challenges and architecture design," in *Proc. Pervasive Comput. Commun. Workshops (PerCom)*, St. Louis, MO, USA, Mar. 2015, pp. 537–542.

[3] S. Sudevalayam and P. Kulkarni, "Energy harvesting sensor nodes: Survey and implications," *IEEE Commun. Surveys Tuts.*, vol. 13, no. 3, pp. 443–461, 3rd Quart., 2011.

[4] X. Lu, P. Wang, D. Niyato, D. I. Kim, and Z. Han, "Wireless networks with RF energy harvesting: A contemporary survey," *IEEE Commun. Surveys Tuts.*, vol. 17, no. 2, pp. 757–789, 2nd Quart., 2015.

[5] X. Zhou, R. Zhang, and C. K. Ho, "Wireless information and power transfer: Architecture design and rate-energy tradeoff," *IEEE Trans. Commun.*, vol. 61, no. 11, pp. 4754–4767, Nov. 2013.

[6] K. Ali, H. X. Nguyen, P. Shah, Q.-T. Vien, and N. Bhuvanasundaram, "Architecture for public safety network using D2D communication," in *Proc. IEEE Wireless Commun. Netw. Conf. (WCNC)*, Doha, Qatar, Apr. 2016, pp. 206–211.

[7] (2016). *Safety Check*. [Online]. Available: https://www.facebook.com/about/safetycheck/

[8] A. Asadi, Q. Wang, and V. Mancuso, "A survey on device-to-device communication in cellular networks," *IEEE Commun. Surveys Tuts.*, vol. 16, no. 4, pp. 1801–1819, 4th Quart., 2014.

[9] M. Hunukumbure, T. Moulsley, A. Oyawoye, S. Vadgama, and M. Wilson, "D2D for energy efficient communications in disaster and emergency situations," in *Proc. IEEE 21st Int. Conf. Softw., Telecommun. Comput. Netw. (SoftCOM)*, Sep. 2013, pp. 1–5.

[10] H. Nishiyama, M. Ito, and N. Kato, "Relay-by-smartphone: Realizing multihop device-to-device communications," *IEEE Commun. Mag.*, vol. 52, no. 4, pp. 56–65, Apr. 2014.

[11] B. K. Chalise, Y. D. Zhang, and M. G. Amin, "Energy harvesting in an OSTBC based amplify-and-forward MIMO relay system," in *Proc. IEEE Int. Conf. Acoust., Speech Signal Process. (ICASSP)* Kyoto, Japan, Mar. 2012, pp. 3201–3204.

[12] C.-H. Lee, "Wireless information and power transfer for communication recovery in disaster areas," in *Proc. IEEE 15th Int. Symp. World Wireless, Mobile Multimedia Netw. (WoWMoM)*, Sydney, NSW, Australia, Jun. 2014, pp. 1–4.

[13] M. Li, H. Nishiyama, N. Kato, Y. Owada, and K. Hamaguchi, "On the energy-efficient of throughput-based scheme using renewable energy for wireless mesh networks in disaster area," *IEEE Trans. Emerg. Topics Comput.*, vol. 3, no. 3, pp. 420–431, Sep. 2015.

[14] M. Nahas, M. Ghantous, K. A. H. Ismaiil, and B. Assaf, "For better energy consumption and management in future cellular networks," in *Proc. Int. Conf. Renew. Energies Developing Countries (REDEC)*, Beirut, Lebanon, Nov. 2014, pp. 127–132.

[15] T. Sakano *et al.*, "Bringing movable and deployable networks to disaster areas: development and field test of MDRU," *IEEE Netw.*, vol. 30, no. 1, p. 86–91, Jan./Feb. 2016.

[16] C. Altay, N. Z. Bozdemir, and E. Camcioğlu, "Standalone eNode-B design with integrated virtual EPC in public safety networks," in *Proc. IEEE/IFIP Netw. Oper. Manage. Symp. (NOMS)*, Istanbul, Turkey, Apr. 2016, pp. 731–734.

[17] L. Xiao, T. E. Fuja, and D. J. Costello, "Mobile relaying: Coverage extension and throughput enhancement," *IEEE Trans. Commun.*, vol. 58, no. 9, pp. 2709–2717, Sep. 2010.

[18] K. Ali, H. X. Nguyen, P. Shah, and Q.-T. Vien, "Energy efficient and scalable d2d architecture design for public safety network," in *Proc. Adv. Commun. Syst. Inf. Secur. (ACOSIS)*, Marrakesh, Morocco, Oct. 2016, pp. 1–6.

[19] G. Huang, Q. Zhang, and J. Qin, "Joint time switching and power allocation for multicarrier decode-and-forward relay networks with SWIPT," *IEEE Signal Process. Lett.*, vol. 22, no. 12, pp. 2284–2288, Dec. 2015.

[20] A. A. Nasir, X. Zhou, S. Durrani, and R. A. Kennedy, "Relaying protocols for wireless energy harvesting and information processing," *IEEE Trans. Wireless Commun.*, vol. 12, no. 7, pp. 3622–3636, Jul. 2013.

[21] Z. Ding, I. Krikidis, B. Sharif, and H. V. Poor, "Wireless information and power transfer in cooperative networks with spatially random relays," *IEEE Trans. Wireless Commun.*, vol. 13, no. 8, pp. 4440–4453, Aug. 2014.

[22] H. H. Yang, J. Lee, and T. Q. S. Quek, "Green device-to-device communication with harvesting energy in cellular networks," in *Proc. 6th Int. Conf. Wireless Commun. Signal Process. (WCSP)*, Hefei, China, Oct. 2014, pp. 1–6.

[23] Z. Li, "Performance analysis of network assisted neighbor discovery algorithms," School Elect. Eng., Royal Inst. Technol., Stockholm, Sweden, Tech. Rep. XR-EE-RT 2012:026, 2012. [Online]. Available:http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-117696

[24] M. Chatterjee, S. K. Das, and D. Turgut, "WCA: A weighted clustering algorithm for mobile ad hoc networks," *Cluster Comput.*, vol. 5, no. 2, pp. 193–204, Apr. 2002.

[25] E. Yaacoub and O. Kubbar, "Energy-efficient device-to-device communications in LTE public safety networks," in *Proc. Globecom Workshops*, Anaheim, CA, USA, Dec. 2012, pp. 391–395.

[26] S. Khan and J. L. Mauri, "Interplay between cooperative D2D communication and green LTE cellular networks," in *Green Networking and Communications: ICT for Sustainability* New York, NY, USA: CRC Press, 2013, ch. 7, pp. 148–155.

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